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METHOD FOR OPTICALLY PUMPING A LIGHT AMPLIFYING MEDIUM AND AN OPTICAL PUMPING MODULE FOR IMPLEMENTING THIS METHOD

TECHNICAL FIELD

The present invention relates to a method for optically pumping a light-amplifying medium as well as to an optical pumping module for implementing this method.

A laser based on the invention finds industrial applications, notably in the following fields: welding, cutting, surface treatment of materials, and labelling of objects.

It may also find applications in the medical field.

STATE OF THE ART

It is known that a laser essentially comprises an amplifying medium and two mirrors forming a resonant cavity, the amplifying medium being placed between these two mirrors.

The energy required for operating a laser may be provided to the amplifying medium, electrically, chemically or optically.

In the present invention, we are interested in the third way, i.e. in what is called the optical pumping of the amplifying medium.

The distribution of pumping light in the amplifying medium should be as homogeneous as possible to reduce the effects which limit the performances of the laser.

Now, if nothing is specifically undertaken in this direction, the distribution of this pumping light is

generally inhomogeneous and it frequently has a maximum on the side of the source of this light.

Right now, let us specify that the invention relates to a method for making this distribution homogeneous.

It is known that the amplifying medium of a laser absorbs the whole or a part of the pumping power and re-emits a certain amount of it as stimulated emission, the remainder of the absorbed power is transformed into heat. This stimulated emission is called the "laser effect".

The absorption of the pumping power follows an exponential law (the Beer-Lambert law) which is expressed by a larger absorbed power on the portion (or the portions) of the amplifying medium near the pumping source. This generates pumping inhomogeneities: the absorbed power is not the same in all points of the amplifying medium.

The pumping power variations in different points of this medium in turn generate local variations of the refractive index which induce deformations of the wave front of the emitted laser beam.

The ultimate consequence of these pumping inhomogeneities is a limitation of the quality of this laser beam. In particular, the deformation of the wave front may limit the extracted power from the laser and increase the divergence of the laser beam.

In the particular case of a solid amplifying medium in the shape of a rod, it is known that these drawbacks are overcome by pumping this medium longitudinally. To do this, the light flux from one or more light sources, for example laser diodes, is focussed on one of the faces of the rod.

With this technique, a homogeneous distribution of the pumping may be obtained but it is not adapted to lasers with very high average power output because of the thermal stress problems of the end of the amplifying medium. In fact this technique is especially adapted to transverse monomode lasers with moderate average power output.

When it is desired to build a laser with high average power output, a known transverse technique is preferably used. A finite number of laser diodes are then positioned radially around the amplifying medium.

This is schematically illustrated by Fig. 1 where in a sectional view, a laser rod 2 is seen placed in a sapphire sleeve 4.

The space between the rod 2 and the sleeve 4 forms a cooling channel 6. Three laser diodes 8 are placed at 120° from one another around the sleeve 4 and are separated from each other by copper spacers 10.

Each diode 8 emits a light beam for optical pumping in the direction of rod 2 and this beam is focussed on the rod via a cylindrical lens 12.

In this known transverse pumping technique, each diode in fact, only illuminates a limited portion of the amplifying medium and the pumping homogeneity which may then be obtained directly, depends on the degree of symmetry of the diodes-rod system.

The more diodes, more the ideal axisymmetric case is approached. Now, in practice, mechanical stresses cause the number of diodes to be frequently limited to 3 or 5.

DESCRIPTION OF THE INVENTION

The object of the present invention is a method

for optically pumping a light-amplifying medium as well as an optical pumping module, which enable this pumping power to be distributed homogeneously, may be used for forming a laser, regardless of the intended power for this laser, and do not require a large number of pumping light sources.

Specifically, the present invention relates to a method for optically pumping a light-amplifying medium, wherein at least one light source is used for optically pumping the amplifying medium and this amplifying medium is encircled by a reflector, the (simple or multiple) wall of which is able to reflect the light of the source, this method being characterized in that the reflector is partly or totally diffusive and in that the beam directly stemming from the source is sent towards the wall of the reflector so that this beam undergoes successive partly or totally diffusive reflections and the amplifying medium is placed out of this beam directly stemming from the source so that the amplifying medium is optically pumped by the sole light reflected by the wall of the partly or totally diffusive reflector.

The invention also relates to an optical pumping module for a light amplifying medium, comprising at least a light source for optically pumping the amplifying medium and a reflector which encircles this amplifying medium and the (simple or multiple) wall of which is able to reflect the light of the source, this module being characterized in that the reflector is partly or totally diffusive and in that the source is orientated so as to send the beam directly stemming from this source towards the wall of the reflector so that this beam undergoes successive partly or totally

diffusive reflections and in that the amplifying medium is placed out of this beam directly stemming from the source so that this amplifying medium is optically pumped by the sole light reflected by the wall of the reflector.

According to a preferred embodiment of the module, object of the invention, the amplifying medium forms a cylindrical rod with a substantially circular base, the light source is for transverse optical pumping of this medium and the wall of the reflector forms a cylinder with its generatrices parallel to the axis of the amplifying medium.

Preferably, the reflector has substantially the same length as the amplifying medium.

The base of the cylinder formed by the wall of the reflector may for example be selected from substantially regular polygons, ellipses and circles.

The light source may be a light emitter.

This light emitter may be selected from a laser diode, a laser diode array, a row of laser diode arrays, a stack of laser diode arrays and a combination of this row and this stack, this (or these) array(s) being parallel to the generatrices of the cylinder which are formed by the wall of the reflector.

The module, object of the invention, may further comprise several blocks, wherein each block comprises a plane face, able to reflect the light of the source in a partly or totally diffusive way, wherein the base of the cylinder formed by the wall of the reflector being a substantially regular polygon, wherein this wall thus comprises several sides, each of the latter being formed by two respective planar faces of two adjacent blocks.

The light source may be placed in a gap formed between two adjacent blocks in such a way that the light emerges from the space thereby formed between the respective planar faces of these two blocks and reaches the wall of the reflector.

According to a particular embodiment of the invention, both blocks are electrically conducting and the laser diode or the laser diode array(s) are electrically powered via both of these blocks.

Instead of being a light emitter, the light source may be a light propagation means, one end of which is for receiving the light from a light emitter and the other end of which is for sending this light towards the wall of the reflector. Preferably, the reflector is quasi-lambertian.

SHORT DESCRIPTION OF THE DRAWINGS

The present invention will be better understood upon reading the description of exemplary embodiments given hereafter, purely as an indication, and by no means as a limitation, with reference to the appended drawings wherein:

- Fig. 1 schematically illustrates a known technique for transverse optical pumping of a light-amplifying medium and it has already been described,
- Fig. 2 schematically illustrates the principle of the present invention,
- Fig. 3 is a schematic sectional view of a first particular embodiment of the optical pumping module, object of the invention, using a reflector with a cylindrical wall and a square base,
- Fig. 4 is a schematic sectional view of a second particular embodiment of the optical pumping

module, object of the invention, using a diffusive reflector with a cylindrical wall and a circular base, and

- Fig. 5 is a schematic sectional view of a third particular embodiment of the optical pumping module subject of the invention, using a diffusive reflector with a cylindrical wall and a polygonal base.

DETAILED DISCUSSION OF THE PARTICULAR EMBODIMENTS

An optical pumping module according to the invention is schematically illustrated as a sectional view in Fig. 2 and comprises a light-amplifying medium 14 and at least a light source 16, for example a laser diode, this source being preferably quasi point-like.

The source 16 is provided in order to provide light able to optically pump the amplifying medium 14.

The module illustrated in Fig. 2 also comprises a reflector 20 which encircles the amplifying medium and the wall of which 22 is able to reflect this light in a diffusive way. This reflector is preferably quasi-lambertian.

The source 16, which opens into the space delimited by the reflector, is orientated so as to send the light beam 18 directly stemming from this source 16 towards the wall 22 of this reflector. This beam 18 then undergoes successive diffusive reflections.

Moreover, the amplifying medium 14 is placed out of this beam directly stemming from the source 16. As a result, this amplifying medium 14 is optically pumped by the sole light diffused by the wall 22 of reflector 20.

In the known transverse optical pumping modules, light sources, for example laser diodes, directly emit

in the direction of the amplifying medium. Homogeneity of the pumping can then only result from the sum of the respective contributions of the laser diodes, by a symmetry effect.

The present invention goes against this principle: no source used in the invention directly emits its light towards the amplifying medium. This is why the optical pumping method of the invention may be considered as indirect pumping.

In the invention, the light flux emitted by each pumping light source all around the amplifying medium is distributed by means of a partly or totally diffusive reflector in order to avoid creating a preferential direction. This source then forms not only a localized source but an extended source which illuminates the amplifying medium in all directions.

It should be noted that quasi homogeneous pumping may be obtained with each source. In the invention, there are therefore less symmetry constraints as in the prior art, both for the mechanical positioning of the sources and for the selective sorting of the latter.

It should also be noted that because a diffusive reflector is used, as the amplifying medium is encircled by this reflector, the shape of the latter is not very important: it may be square, polygonal, round or of any other shape.

For example, this reflector may be made in ceramic of the SINTOX-A1 (registered trademark) type or in polymer of the SPECTRALON (registered trademark) type or be obtained by means of a surface treatment of a metal wall, for example a treatment of the INFRAGOLD (registered trademark) type during which the metal wall is sandblasted and then a thin gold layer is deposited

thereon.

Let us now consider the transverse optical pumping modules which are schematically illustrated in Figs. 3-5. In each of these modules, a diffusive reflector 20 and an amplifying medium 24 in the shape of a cylindrical rod with a substantially circular base are coaxial and approximately of the same length. These pumping modules are seen in a sectional view perpendicular to axis X which is common to the amplifying medium and to the reflector.

A module according to the invention may be used not only in a laser (strictly speaking) but also in a light-amplifying device where a laser beam crosses an light-amplifying medium for amplifying this beam.

If the modules of Figs. 3-5 are applied to a laser, it is specified that both mirrors of the laser cavity, which delimit this cavity, would be perpendicular to the X axis and respectively placed on either side of the amplifying medium 24.

In the examples of Figs. 3-5, this amplifying medium 24 is solid. It is placed inside a tube 26 which is transparent to the pumping light. In the gap 28 between this tube and the amplifying medium, a cooling liquid transparent to the pumping light is caused to flow by means not shown, in order to cool the amplifying medium.

The reflector 20 encircles the tube 26 and therefore the amplifying medium 24 and the wall 22 of this reflector forms a cylinder with its generatrices parallel to the X axis of the amplifying medium.

In the examples of Figs. 3-5, one or more light sources for optical pumping are used, for example one or more laser diodes with an emission spectrum in

accordance with the absorption spectrum of the amplifying medium.

As an alternative, the light emitted by the laser diodes may be brought inside the pumping chamber delimited by the diffusive reflector, for example by means of optical waveguides, optical fibers or simple slits (made reflecting as regards the pumping light).

The thereby injected light in the pumping chamber is first directed on the diffusive reflecting material, directly without passing through the amplifying medium.

In the example of Fig. 3, the reflector wall is a cylinder with a square base: the four sides of this wall are seen in the figure.

Four optical pumping light sources 30 are used, associated with the four sides respectively. Each of these sources 30 comprises an optical waveguide 32, for example a glass strip, which crosses the reflector parallel to the X axis as seen in Fig. 3.

A first end of this strip 32 opens into the inside of the reflector and is flush with the wall of the latter whereas the second end of the strip opens into the outside of this reflector.

This second end is optically coupled with a laser diode 34 or with a laser diode array parallel to the X axis, which is driven by means not shown.

This diode or this diode array emits the pumping light which is then transferred by the strip and emerges from the first end of this strip so as to illuminate the wall of the reflector.

The inclination β of each strip with respect to the wall and the distance d of the first corresponding end with respect to an adjacent side of this wall is selected so that the light beam 18 stemming from this

first end illuminates the wall without encountering the amplifying medium 24, the aperture angle α of this beam (see Fig. 2) being known.

Purely as an indication and by no means as a limitation, the following are used

- an amplifying rod in Nd:YAG with a diameter of 5 mm and an optical index of 1.82,
- laser diodes with 40° total divergence at half maximum, which are positioned at 0.5 mm from their respective light waveguides, emit at 808 nm and have a spectral bandwidth of 2 nm at half maximum,
- a glass tube 26 with an internal diameter of 7 mm and an external diameter of 9 mm and an optical index of 1.5, this tube having received an anti-reflecting treatment on the outside,
- coolant water with an optical index equal to 1.33
- a reflector with a 15 mm sided square wall and having a reflection coefficient of 97.5% and
- glass optical waveguides with dimensions 1 cm x 1 mm, which have an optical index equal to 1.5 and with first and second ends having received an anti-reflecting treatment.

In the example of Fig. 4, the reflector 20 has a cylindrical wall with a circular base. Five optical pumping light sources 30 are used.

Each source comprises an optical fiber 36, one end of which is optically coupled with a laser diode 34 driven by means not shown and the other end of which is located in a rectilinear ferrule 38 which crosses the reflector obliquely (i.e. non-radially) in order to open into the space delimited by this reflector, while being flush with the wall of this reflector.

The light beam 18 directly stemming from the end of the ferrule is seen in the space delimited by the wall 22. This beam further illuminates this wall without encountering the amplifying medium.

In the example of Fig. 5, the diffusive reflector 20 has a cylindrical wall 22 with a, for example 5-sided, polygonal base.

Light emitters 40 formed by laser diode arrays which are parallel to the X axis of the amplifying rod 24 are used as pumping light sources.

Superpositions and/or stacks of such arrays may also be used.

Five groups of two metal blocks 42 and 44 with two planar faces 46 and 48 respectively, are seen in Fig. 5, which are coplanar and the joining of which forms one of the sides of the wall 22 with a pentagonal base of the module of Fig. 5.

Each laser diode array is located between both metal blocks 42 and 44 of a same group and in the vicinity of the respective faces 46 and 48 of both of these blocks, on the line separating both of these faces.

With this, the laser diodes of this array may be electrically powered by biassing both blocks in an appropriate way, by means in Fig. 5, symbolized by the - and + signs associated with the blocks 42 and 44, respectively.

The existing space between these two blocks is seen in Fig. 5, which is partially occupied by the corresponding array 40. The remainder of this space is filled with an electrically insulating material 50.

It is seen that this space is oblique with respect to the respective planar faces 46 and 48 of both blocks

42 and 44 and that the illumination of the wall of the reflector is again oblique in the case of Fig. 5, as the light beam 18 directly stemming from the array does not encounter the amplifying medium 24.

Also, a component 52, made in an electrically insulating material, separates each block, belonging to a determined group of blocks, from a block of the adjacent group in order to prevent any electrical contact between these two blocks.

Further, all the faces 46 and 48 are sandblasted and then coated with a thin gold layer in order to obtain the diffusive reflection.